Study of Electromagnetic Data Applied to Hydrogeology, in the region of Serrinha RN

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Abstract

The long and intense droughts that occur in the Northeast of Brazil aggravates socio-economic problems in the region. The lack of water affects not only the local subsistence but the large-scale plantation economy. The difficulty in exploiting water resources brought the necessity to find an arbitrary way to obtain it, such as underground water wells. The PROASNE-Brasil project aims to improve living conditions in the northeastern region of Brazil, by providing sustainable solutions to the problems caused by drought. Among the technologies that offer better perspectives, aerial geophysics stands out. More specifically, electromagnetic methods in the frequency domain, which can potentially be a valuable tool for mapping the distribution of groundwater resources in crystalline basement environments. That extends across approximately 80% of the millions of square kilometres in northeastern Brazil that are affected by drought.

Introduction

The aim of the Groundwater Project in the Northeast (PROASNE-Brazil), developed jointly with specialists from different areas and technical institutions such as the Geological Survey of Brazil (CPRM) and the Geological Survey of Canada (GSC), endeavoured to develop sustainable solutions for the needs caused by drought. Among several technologies, aerial geophysics offered a better perspective of the case, accurately the electromagnetic methods in the frequency domain, a tool of great potential in the study and mapping of the distribution of underground water resources in environments of a crystalline basement that make up the majority of northeast Brazil affected by drought.

As part of this project, where electro magnetometry data were acquired, the Serrinha region, which is located in the Serrinha county, Rio Grande do Norte, delimited by the coordinates UTM: 209000E - 222000E / 9305000N - 9313000N and is limited geographically by São José do Campestre, Lagoa de Pedras, Santo Antônio and Lagoa Salgada, the survey area is 104 km² (PROASNE) and it is located in the southeastern portion of RN.

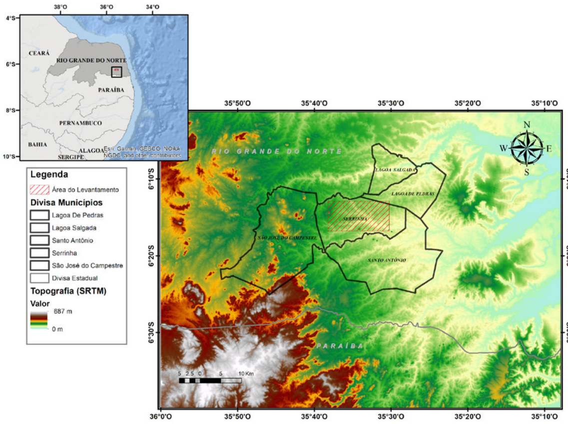

Figure 1: Location and topography map of the study area, Serrinha / RN.

The rainfall is irregular over the year, presenting seven dry months, June to December (Nimer et al., 1979), and the average annual rainfall in Custodia is 708.8 mm (Morais et al., 1999). There are no surpluses in the water reserves of the soil during March, April, and May, because those are used. The average annual temperature is 23.5ºC.

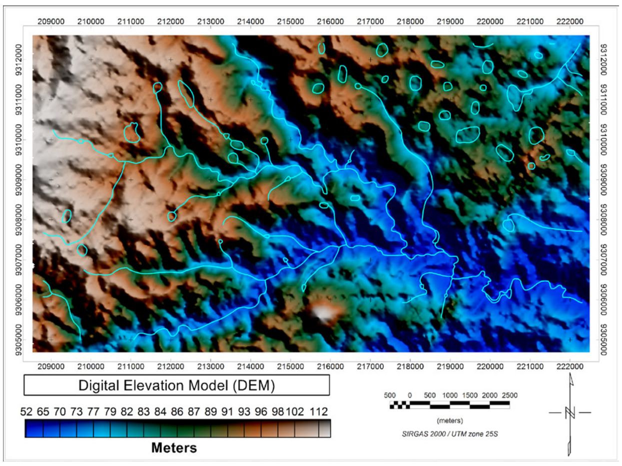

Figure 2: Digital elevation and hydrography model of the survey area

Method and Materials

Geology

The geological data were obtained through the geo-bank (geoSGB) of FOLHA SB.25-YAI - SÃO JOSÉ DO CAMPESTRE, acquired by the Ministry of Mines and Energy and the Geological Service of Brazil (CPRM), the geological chart is on a scale of 1: 100,000. The survey area is located in the Precambrian of the Borborema Province (Almeida et al., 1977), inserted, more specifically in the Maciço São José do Campestre and located to the east of the Seridó Fold System (Brito Neves et al., 1983). This configuration refers to a complex mosaic of gneissic blocks, delimited by shear zones and intruded by granite bodies of the Brasiliano age where it is possible to identify ductile deformations in the southeastern portion, referring to the Rio Jacu Shear Zone, and NNE and NW fractures from an oldest tectonic episode. In addition, there are fractures, not as a representative, with EW direction in the centre-east of the area.

Among the lithological types present in the São José do Campestre leaf, the survey area is predominantly composed of Neoproterozoic to Paleoarquean rocks. The oldest and deepest units in the stratigraphic session (Figure 3) are the Presidente Juscelino Complexes (stromatic migmatites, banded to nebulites, containing garnet) and Brejinho (orthogneiss-granodiorite to predominant granites, including metatonalites), rocks close to 3200 (Bad). In local geology, it is important to highlight the sedimentary rocks of the Colluvium-eluvial deposits which, according to the CPRM Groundwater Supply Source Project, are inserted in the Interstitial Hydrological Domain whose characteristic is high porosity, that is, high propensity to storing water. And the Pedro Velho and Presidente Juscelino Complex, in turn, represent the Fissural Hydrological Domain characterized by impermeable crystalline basement rocks that contain cracks from fractures that allow water to circulate.

The crystalline basement represents 70% of the semiarid region, (Carvalho et al., 1973). Crystalline rocks receive this name due to their composition of crystallized minerals that give specific characteristics of resistance and deformability, so there is a possibility of the existence of water in the subsoil due to fractures and alluvium. The area of interest combines the susceptibility of fractured crystalline rocks to store groundwater with the semi-arid climate of the Northeast region. Such factors influence the storage and composition of the water, causing problems of salinization and even unproductiveness of the drilled wells.

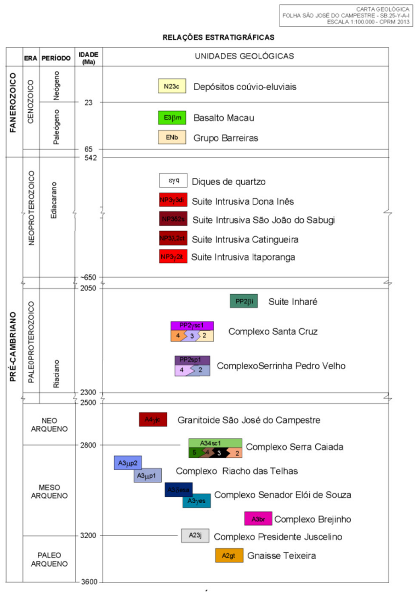

Figure 3: Stratigraphic column (Folha São José do Campestre - SB.25.Y.A.I)

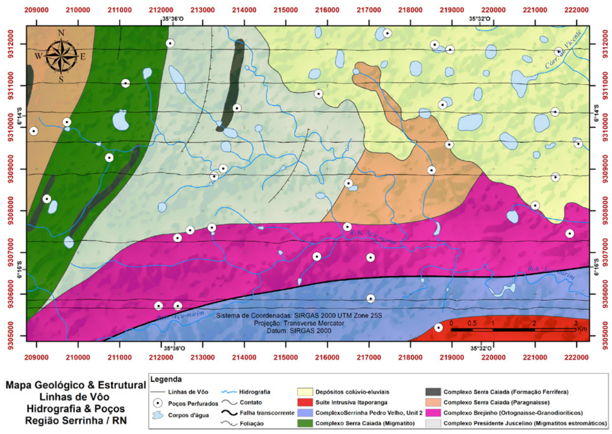

Figure 4: Geological map of the airborne geophysical survey area inductive Electromagnetic Method

The Electromagnetic Induction Method

The active electromagnetic methods are based on the contrast of the electromagnetic properties of the soil. The feasibility of using this method to study an anomalous body depends on the contrast of properties of the environment around it, the nature of the materials, the depth, the way they are arranged, and their proximity to the water table. If these contrasts are large enough, then the anomalies will be detected.

The methodology applied in this work is based on the basic theory of the electromagnetic method in the frequency domain. The theoretical basis consists of circulating an alternating electric current, which has a constant frequency, in a transmitting coil (Tx), resulting in a primary electromagnetic field (Hp). The propagation of this field underground, where the conductive medium induces secondary electrical currents that produce a secondary electromagnetic field (Hs) proportional to the induced current. A part of the secondary field induces electric currents in a receiving coil (Rx), positioned within the area of influence of the primary and secondary fields. The potential difference (d.d.p.) associated with the electrical current induced in the receiving coil is directly proportional to the electrical conductivity of the terrain. Assuming that the ratio between Hs and Hp is linear, it is possible to take direct readings of the electrical conductivity of materials in the subsurface, by measuring the values of both fields (McNeill, 1990).

$$\sigma = \frac{4}{\omega \mu_0 s^2} \frac{Hs}{Hp}$$

where f = frequency of the electric current flowing in the coil (Tx), in Hz; ω = angular frequency, in rad / s; = magnetic permeability of the vacuum, in H / m; s = spacing between coils Tx and Rx, in meters. This relation allows the construction of instruments that make a direct reading of the electrical conductivity (Siemens/m) at a predetermined depth. The apparent conductivity was calculated based on the pseudo-layer model defined by (Fraser et. al. 1978). This model consists of a resistive layer over a conductive semi-space, and images of the conductivity were obtained for three frequencies and two geometries (coaxial and coplanar). In this work, the images of conductivity in coplanar geometry will be analyzed as they present better resolution

Conductivity-Depth Image (CDI)

The ICD is a section of conductivity by the depth that represents here an interpretation of airborne EM data. The purpose of imaging is to transform the responses obtained through the AEM method to an image of conductivity by depth (CDI) and thus extract information from the target's geometry and conductivity to facilitate geological interpretation (Huelsen et al., 2007). The sampled relationship of apparent conductivity to depth is given by:

$$\delta = \left(\frac{2}{\omega\mu\sigma}\right)^{1/2} = K\left(\frac{1}{f\sigma}\right)^{1/2}$$

Where delta (δ) is the depth of penetration, given by the relationship between frequency and conductivity of the medium and a K factor, this equation is called the skin-depth equation.

The processing of magnetic data was also carried out, which will not be detailed here in this work but will be used in the magnetic interpretation represented by the analytical signal of the anomalous magnetic field and by the Euler solutions that will join the obtained CDI's.

Acquisition and Processing

The data used for the development of this article were obtained by LASA Engenharia e Prospecções S/A employing an airborne electro-magnetometric survey with an artificial source in the frequency domain (FDEM). This is part of the PROASNE project (Underground Water Project in Northeast Brazil) developed by the partnership between the Geological Service of Brazil (CPRM) and the Geological Service of Canada (GSC), whose main objective was to research the conditions of water storage and percolation underground in crystalline terrain.

The data acquisition phase was carried out through an HB-350 helicopter (Esquilo), equipped with various geophysical equipment, among them the 5-frequency electromagnetic system (FDEM), Aerodat DSP 99, with a towed sensor by a towed bird cable, with the following configuration: 3 pairs of horizontal and coplanar coils (CP1 ~ 900 Hz; CP2 ~ 4500 Hz; CP3 ~ 33,000 Hz) and two pairs of vertical coils (CX1 ~ 900 Hz; CX2 ~ 4500 Hz). The system allows 10 readings per second of the phase and quadrature components of each of the five frequencies. The data survey adds up to 4,465.7 km of electromagnetic profiles (Proasne). The flight (LV) and control (LC) lines were acquired and spaced from 100m and 500m, and the directions of the lines were E-W (LV) and N-S (LC). And the georeferencing was acquired through the GPS (Novatel), 12 channels.

Data processing was performed using the GEOSOFT ™ software (Geosoft, 2019), Oasis Montaj. The data interpolator method used was Krigagem. The applied filters were Hanning and Directional Cosine, adjusting the necessary parameters for each conductivity image. 3 conductivity images were generated using the three frequencies: low (900 Hz), medium (4,500 Hz), and high (33,000 Hz) for the coaxial and coplanar arrangements, but here the best results, which were from the coplanar arrangement, will be presented. Figures 5, 6, and 7 were more representative images to identify geophysical structures with groundwater storage potential, relating them to the high conductive. We observed that low-frequency conductivity images, which represent the deepest conductors, have a lower signal-to-noise ratio, even with the filters used. It can be observed that to the northwest of the area a high conductive with a great extension and some lines with approximately N-S direction prevails. In the southern part of the area, there are few and extensive conductive lines with NE-SW and E-W direction.

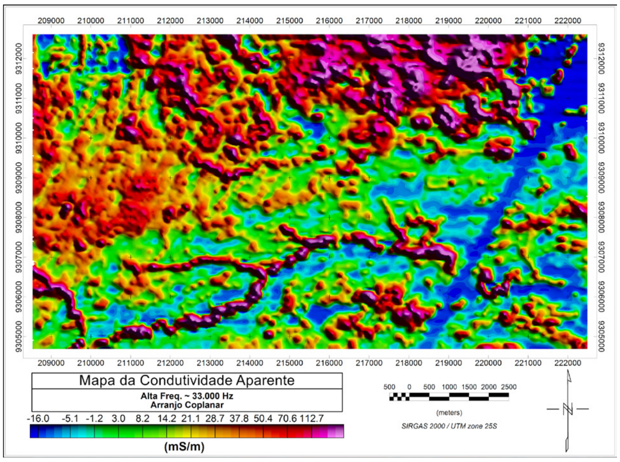

Figure 5: Secondary Field - High Frequency

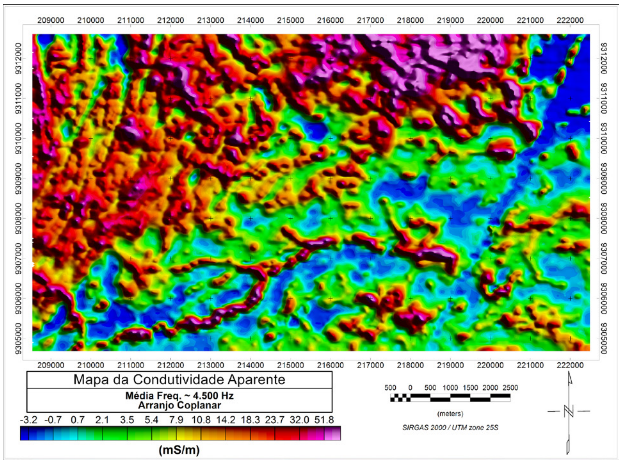

Figure 6: Secondary field - Medium frequency

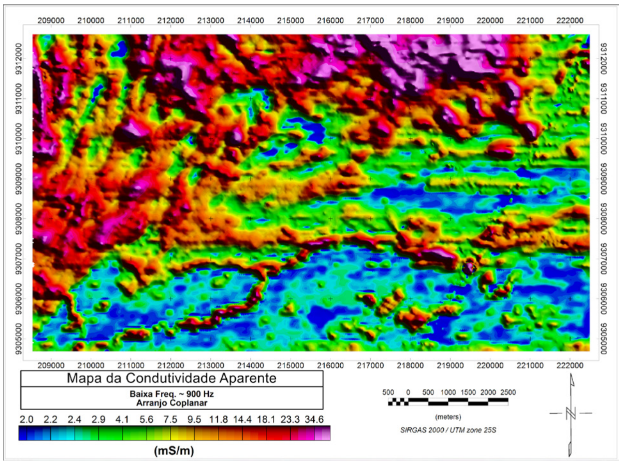

Figure 7: Secondary field - Low Frequency

Results and Discussions

Ternary Image (CMY) of Conductivity

A CMY ternary image composition was performed with high frequency (Cyan), intermediate (Magenta), and low (Yellow) coplanar conductivities (Figure 8). The area in (cyan) represents shallow bodies, (magenta) intermediate bodies, and (yellow) deep bodies. The darkened or black areas show the conductive targets that present themselves from low to high depths, the cyan region represents the shallow targets, which may be due to the presence of the oxisol and in yellow the deep targets stand out. The low conductivity SW-NE lineation in the channels from shallow to intermediate (high and medium frequency) is quite noisy due to its low signal/noise ratio, with great difficulty in removing it through filtering and in the interpretation of the image.

The northwestern quadrant of the map shows the high conductors and it is possible to notice a NE / SW boundary dividing the area into high and low conductivity. The northeast portion is strong with the presence of shallow to a deep conducting body of the great extension, generating a sub-area within the conductive area to NW, where structures with NW / SE direction are observed, accompanying the hydrogeology and the lithological contact between the deposits. eluvial colluvium and the Presidente Juscelino Complex. The south area shows a thin and extensive line from NE / SW to E-W, associated with the course of the Açu-Mirim stream.

Hydrographic information and mapped geological structures were added to the image (figures 8), as well as information from tubular wells registered in the Groundwater Information System (SIAGAS-CPRM), to become complementary tools for the interpretation and understanding of the environment. hydrogeological area of Serrinha and the conductive lines of the area. In addition, the vectorization of the high and low conductors was carried out through rasterization of the CMY image (Figure 9) to highlight the shallow to deep conductors in isolation.

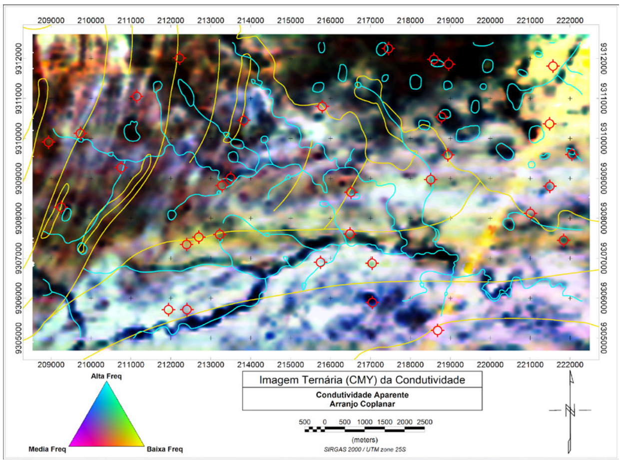

Figure 8: Ternary image (CMY) of conductivity with overlapping geological structures (yellow line), hydrography (blue line), and tubular wells (red circles).

Integrated with the structural and hydrological data, in addition to the position of the wells to the ternary conductivity map (figure 8), in the southern region of the map, it was possible to identify a correlation between the thin and extensive NE / SW, E / W conductive lines with the hydrography of the precisely to the Açu-Mirim stream, showing the high conductivity from shallow to deep levels associated with hydrogeological environments, as it is a zone with a high tectonic precedent, the fractures, and foliations present are significant when associated with local hydrogeology. In addition, a part of the conductive lineation and the Açu-Mirim stream is cut by a geological structure of the type passing fault, this area is subparallel to the direction of maximum compression, and therefore, it is an important structure of recharge and accumulation of water Silva, 2004). Very close to the fault there are two wells drilled.

From the northeast of the area, descending towards the central portion of the map, we can see the central boundary between the high and low conductive, highlighted in the (figure 9) red dashed line.

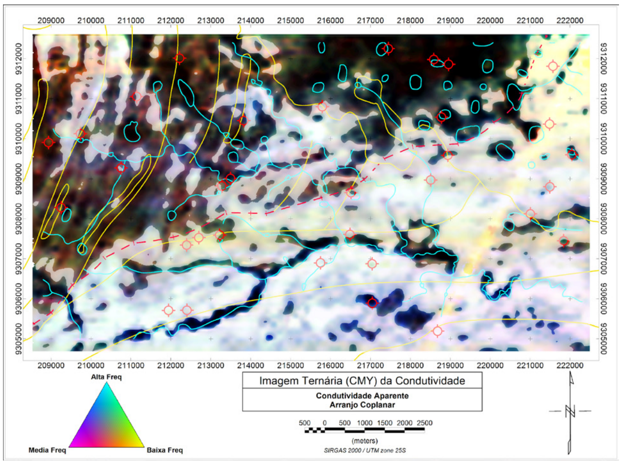

Figure 9: CMY image of isolated conductive targets, hydrography (blue), geological structures (yellow), wells (red circle), and limit between high and low conductivity (dashed line - red).

Many of the conductive lineaments accompany geological contacts. Among them, the fine and extensive line to the south of the map follows the contact of the Presidente Juscelino / Brejinho Complexes and the Brejinho / Pedro Velho Complex, a region associated with the formation of alluviums and regolith. In the northern portion of the map, the body of greater conductivity and great extension is associated with colluvium and eluvial deposits, sedimentary rocks with the potential of interstitial hydrogeological domains, and in the northwest region the lineaments accompany the contact of the Presidente Juscelino / Serra Caiada Complexes.

Conductivity-Depth Image (CDI)

The survey lines have W-E direction, and to perform the CDI (Conductivity Depth Image) the flight line selected was the L30060 located in the northern portion of the survey area. This selected line is inserted in the context (EW direction) of the Colluvium-Eluvial deposits, which predominates the interstitial hydrological domain and of high porosity, and the Presidente Juscelino Complex characterized by the fissural hydrological domain, which is characterized by the impermeable and fractured crystalline basement rocks and the Serra Caiada complex (paragneiss-migmatites).

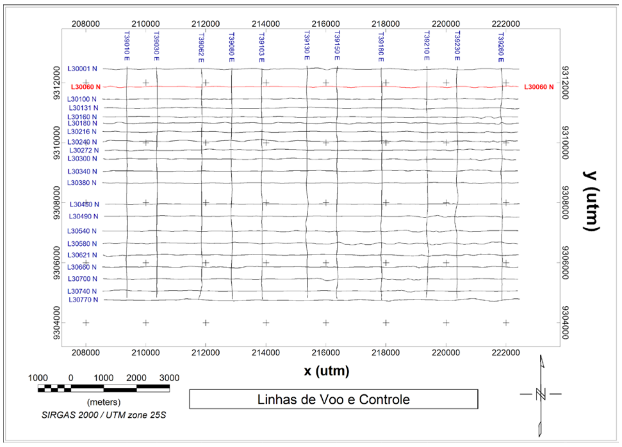

Figure 10: Flight Lines. In red, highlight the CDI line that will be sampled.

Together with the selected CDI, the stacked profiles of the high (HI), medium (ME), and low (LO) frequency channels of the secondary field were inserted, in coplanar (CP) and coaxial (CX) geometry. In addition relief information (DEM), the amplitude of the analytical signal of the Magnetic Field (ASA), tubular wells located in its vicinity, and solutions of magnetic Euler structural index 1 for identification of structures in depth. This information was integrated into the ICD for joint interpretation indicating relatively deep magnetic structures associated with high conductive in shallow regions, characterizing areas of hydrogeological interest.

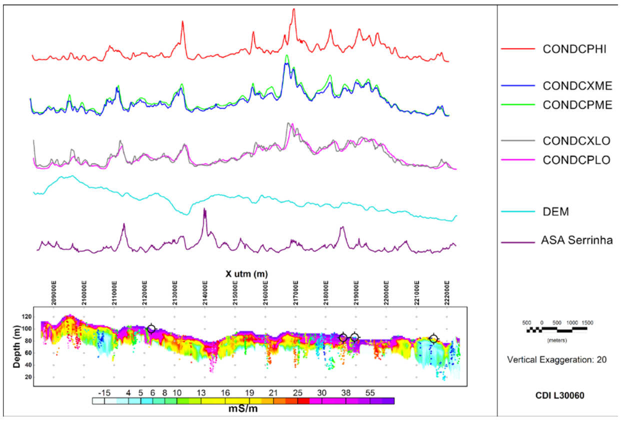

Figure 11: CDI (component z), stacked profiles of the secondary field conductivity (coaxial and coplanar), relief (DEM), the amplitude of the magnetic analytical signal (ASA), and magnetic Euler solutions.

The CDI reaches a depth close to 40 meters and in general, there is a shallow layer of high conductivity, which may be associated with the lateritic and regolith layers. It is evident a medium/high conductivity and high magnetic response between the 209000/210000 coordinates in the context of the Serra Caiada formation (Paragnaisse) and high conductivity and an intermediate magnetic response between the 211000/213000 coordinates region of transitional contact between the Serra Caiada formations and Presidente Juscelino, a tubular well exists close to the lithological contact. Among the coordinates, 214000/215000, a highly conductive and magnetic response associated with structures in-depth, transitional contact, and drainage are observed, which may indicate a possible hydrological recharge region. Finally, the regions between the coordinates 216000/220000 inserted in the colluvium-eluvial deposits observe high conductivity and medium / high magnetic responses in-depth, showing sub-vertical structures not geologically mapped and prone to accumulation of groundwater.

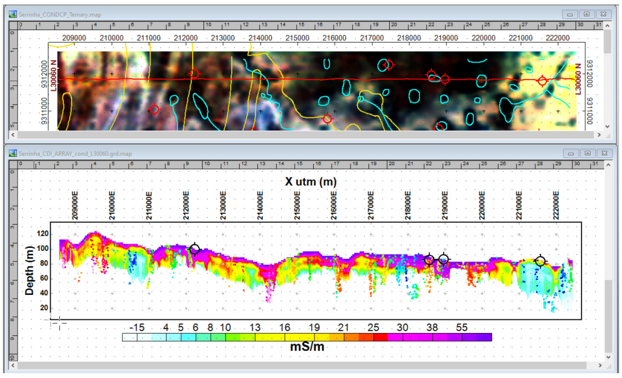

Figure 12: CMY image, flight line 30060 highlighted (red line), hydrography (blue), geological structures (yellow), wells (red circle), and CDI with Euler solutions.

Conclusions

The joint analysis of high-resolution aerial geophysical data and its generated products integrated with geological and hydrogeological data were extremely important for the performance of the study and interpretation of conductive structures associated with groundwater and hydrogeological environments, becoming an essential tool for the realization of qualitative data analysis work. The use of the ternary composition map (CMY) integrated with geological, hydrogeological, and CDI data has become an extremely relevant tool for a first analysis of the Serrinha region and identification of structures with high hydrogeological storage potential. With the knowledge of the location of the bodies and conductive lineaments, the results obtained give a better orientation and view of the hydrogeological environment for future projects and locations of new tubular wells in the region, reducing the chances of drilling dry wells and increasing the efficiency and effectiveness in new perforations.

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